Upgrading of Egyptian Nonsulfide Zinc Ore by Gravity Separation Techniques

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Abstract*-This paper aimed at evaluation and beneficiation of a nonsulfide zinc ore from Um Gheig deposits in the eastern desert of Egypt using gravity separation process. The zinc ore of Um Gheig is called "calamines". It consists of a mixture of zinc carbonates (smithsonite, hydrozincite) and zinc silicates (hemimorphite), with variable amounts of Pb bearing minerals. The ore sample has 47.5 % ZnO, 1.55% PbO and ~29.3 % L.O.I. Liberation study, using mineralogical and SEM investigations, indicated that maximum liberation can be obtained by grinding the ore to 0.125 mm. Beneficiation techniques involved crushing and grinding of the ore to 100 % -0.125 mm. This was followed by classification of the ground ore using a 0.080 mm screen. Shaking table was used to upgrade the coarse fraction (-0.125+0.080 mm) while the fines below 0.080 mm was separated by Falcon concentrator. The results of shaking table showed that a high grade concentrate can be obtained at the following optimum parameters: inclination angle (4 degree), stroke length (2.5 cm), feed rate (150 gm/min), and water flow rate (25 l/min). At such optimum conditions maximum grade (62.2 % ZnO) and operational recovery (~ 93.8 %) were obtained. In the mean time, Falcon concentrator gave a concentrate of 54.85 % ZnO with 76.6% operational recovery from the fine fraction below 0.080 mm.

Keywords-Nonsulfide Zinc Ore; Mineralogy; Petrography; Liberation Size; Gravity Separation; Shaking Table

I. INTRODUCTION

The Um Gheig area is a part of the coastal plain of the Red Sea Coast, Egypt. It lies 38 km south of the city of Quesier (Fig.1). The area can be reached by Quesier-Marsa Alam asphalt road. The Um Gheig mine is located in Wadi Um Gheig, 7.5 km from the west of the Quesier-Marsa Alam asphalt road.

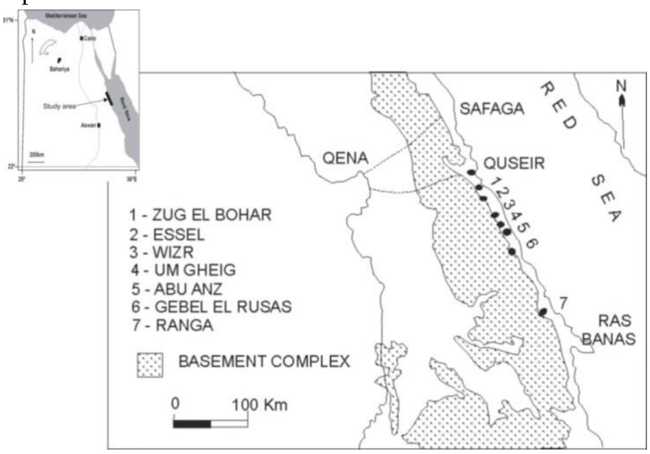


Fig. 1 Location map of the Zn occurrences along the Red Sea coastal zone, Egypt

Um Gheig ore is a nonsulfide Zn (Pb) deposit with estimated resources of about two million ton with an average grade of 10 % Zn, 2 % Pb (Hitzman et al 2003). "Nonsulfide zinc" is a very general term, which comprises a large series of minerals (Large, 2001). The only minerals of current economic importance are the carbonates smithsonite and hydrozincite, and the silicates hemimorphite, willemite, as well as Zn smectite. The economic value of zinc nonsulfide ores is thus dependent not only on the geologic setting of each deposit but also on the specific characteristics of the mineralogical association and the nature of the gangue minerals (Woollett, 2005; de Wet and Singleton, 2008).

During the last decade, with the development of solvent-extraction and electro-winning processes for the treatment of nonsulfide zinc ores, there has been a renewed commercial interest for this type of mineralization throughout the world (Large, 2001). The commercial exploitation of nonsulfide deposits, commonly defined as "Zinc Oxides" or "Calamine" (nonsulfide Zn ore in carbonate rocks), is rapidly becoming an important source of metallic zinc. Moreover, it is foreseeable that in the near future the annual production of zinc from these ores could exceed 10% of the global zinc metal production. Scientific research is now focused not only on several economic "Zinc Oxide" deposits throughout the world (Hitzman et al., 2003) but also on older mining districts containing smaller and historically exploited deposits (Boni and Large, 2003). Compared to sulfide deposits, their main attraction lies in: a) their distinct scarcity or lack of Pb, S and other undesirable elements, b) their relatively low-energy recovery by SX-EW, and c) the generation of higher economic value on site.

A wide series of papers exist on the traditional treatment of nonsulfides (including flotation processes), spanning the first seventy years of the last century (Rey et al., 1954; Billi and Quai, 1963; Caproni et al., 1979). On the contrary, there are not as many recent published studies on the hydrometallurgical behavior of nonsulfide Zn minerals (Bodas, 1996; Abdel-Aal, 2000; Loan et al., 2006; Souza et al., 2007), because most mining companies are still in the experimentation phase.

The main goal of the present study is to separate nonsulfide zinc bearing minerals from their gangues of Um Gheig mine through several beneficiation steps comprised of mineralogical investigation, liberation study and gravity separation "shaking table" tests.

II. EXPERIMENTS

A. Sample Preparation and Characterization

A representative sample from Um Gheig mine, Egypt, was subjected to crushing by a "Denver" jaw crusher. Then the

sample was divided into equal batches using coning and quartering method. One of these batches was further representatively divided into 5 kg equal batches. One of the latter was further splitted into 250g equal batches using a "Jone Riffle" sampler. A sample of them was ground for complete chemical analysis by X-ray fluorescence and X-ray diffraction for mineralogical analysis. Wet-dry size analysis using a series of ASTM standard sieves was performed. After screening, each size fraction was collected, weighed, and chemically analyzed for ZnO %. The degree of liberation was investigated, by an optical microscope, where each size fraction of mineral particles was mounted on thin sections and then analyzed by optical microscope.

Fig. 2 Wifely Shaking Table Unit1: Sample feeding box, 2: Washing water feeding box, 3: Washing water, 4: Heavy products reservoirs, 5: Light products reservoirs

B. Shaking Table Experiments

A "Wilfley" shaking table was used in this study, Fig.2. Four parameters are studied. These parameters are namely, inclination angle, stroke length, feed rate, and water flow rate. The feed to separation experiments was prepared by grinding using a ball mill in closed circuit with 0.125mm sieve. The ground product was further deslimed at 0.080mm screen. The experiments were carried out at feed size fraction −0.125+ 0.08 mm where maximum liberation can be attained.

Fig. 3 Falcon SB40 concentrator

C. Falcon Concentrator

Centrifugal concentration tests were performed using a Falcon SB40 concentrator unit (Fig. 3). These tests were performed on the fine fractions below 0.080 mm. These experiments were performed at the following pre-determined optimum conditions: centrifugal field 200 G's, fluidization water 6 psi, and feed rate 100 gm/min.

III. RESULTS AND DISCUSSION

A. Characterization of Nonsulfide Zinc Ores

The identification and characterization of minerals are of fundamental importance in the development and operation of mining and mineral processing systems (Hope et al., 2001), and they are very important in designing a suitable flow sheet for recovering the valuable metals. It is also critical in optimizing actual plant for improving performance (Xiao and Laplante, 2004). The X-ray diffraction (XRD), chemical analysis, liberation study, and mineralogical investigation were used to determine the main components of the ore as well as the liberation degree which significantly affects the separation results in terms of grade and recovery. Table I gives the mineralogical and chemical composition of the non-sulphide zinc minerals and their associated gangue minerals.

TABLE I THE MINERALOGICAL AND CHEMICAL COMPOSITION OF THE REPRESENTATIVE SAMPLE

Mineralogical composition

smithsonite	hydrozincite	hemimorphite	Calcite	Goethite	Halite	Quartz
50.74	18.78	14.78	15.72	2.86	0.48	1.03

Chemical composition

ZnO	PbO	CaO	Fe_2O_3	SiO_2	MnO	SO_3	Cl	Na_2O	MgO	L.O.I
47.50	1.55	8.01	4.07	4.34	1.03	0.56	2.01	0.36	0.56	29.33

L.O.I= loss of ignition at 1100° C

Table I shows that smithsonite is the major non-sulphide zinc minerals where it represents about 50.7 % in weight, whereas hydrozincite and hemimorphite represent ~18.8 % and 14.8 % respectively. On the other hand, calcite (15.8 % in weight) is the major gangue minerals with minor amounts of goethite (2.8 %).

Mineralogical analysis (using polarized microscope and SEM) showed that there are two generations of smithsonite. Smithsonite occurs as dull, cryptocrystalline with no visible crystals (Fig. 4a). The second smithsonite generation (late smithsonite) occurs as clear rhombohedral crystals, precipitate in vugs and open space of the high grade ore (Fig. 5a). Hydrozincite occurs in different generations in the samples, the first hydrozincite generation occurs as veins growing in smithsonite; veins occur as thin, small veins (Fig. 4b), hydrozincite also occurs as nodules growing in the cavities between smithsonite (Fig. 4c) and botryodial hydrozincite (5b). Two hemimorphite generations could be observed. The first generation occurs as small concretions growing in fine-grained smithsonite (Fig.4d). The second one appears as clear elongated crystals growing in veins and cavities (Fig. 4e). Calcite associated with supergene Zn-Pb mineralization is relatively common, with crystals filling the vugs and open

space in several samples (Fig. 4f), and is also found as precipitate on the mineral surface.

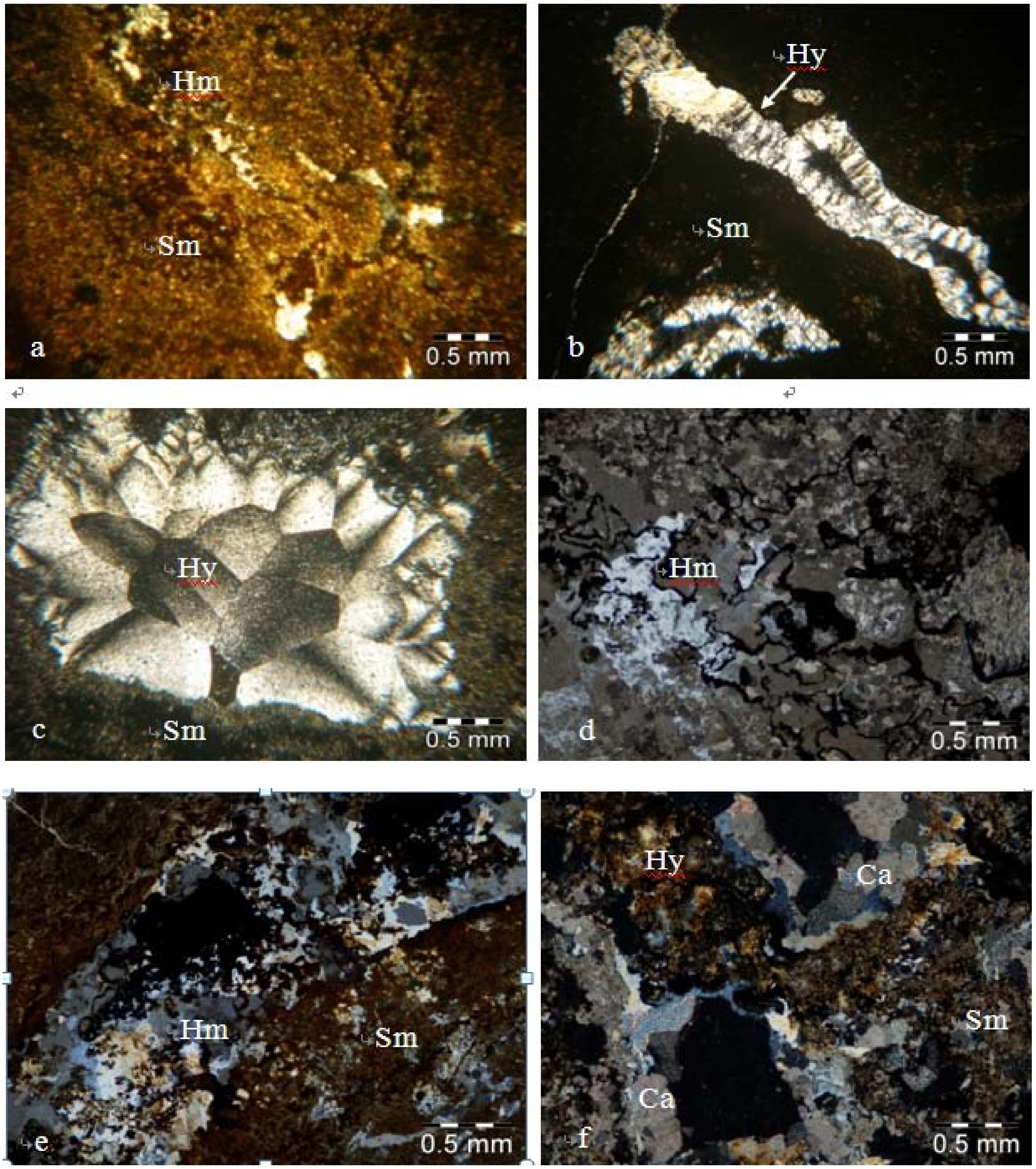


Fig. 4. a) Smithsonite (Sm) fine ground mass, cryptocrystalline, with no visible crystals. b) Hydrozincite (Hy) veins growing in smithsonite mixed with iron oxide. c) Hydrozincite nodules growing in smithsonite. Note that, hydrozincite grade from fine small crystals to large hydrozincite crystals. d) Hemimorphite (Hm) with a dusty appearance inter growing in fine grained smithsonite (first generation). e) Elongate hemimorphite veins growing in open space between smithsonite (Second generation). f) Calcite (Ca) precipitate and filling in the vugs and open space

B. Determination Degree of Liberation

Measurement of the degree of liberation of the minerals, a property directly related to the particle composition distribution as a function of particle size, was an extremely complex problem. However, optical or SEM images (back scattered electrons or X-ray spectra) are becoming faster and more efficient in studying the liberation of ores (Gu & Guerney, 1999).

In this study, each size fractions of mineral particles were mounted on thin sections and, then, analyzed by optical microscope. To achieve relatively high grades and recoveries in mineral processing; the valuable mineral must be individualized to almost mono-mineral particles by grinding operations prior to the physical concentration process.

Fig. 6a and 6b show complex interlocking and growth between non-sulphide Zn minerals (smithsonite, hydrozincite and hemimorphite) and calcite gangue minerals. Figure 6c shows that interlocking between non-sulphide Zn minerals and calcite is less complex "ternary particle". Fig 6d shows that

the grain boundaries of smithsonite, hydrozincite, hemimorphite and calcite have little interpenetration (usually binary interlocking); Figs 6e and 6f show that about more than of 90% fraction of the valuable non-sulphide Zn minerals (liberated) to consider a particle as "free". Very good mineral liberation (>90%) was attained at 0.106 mm, as individual component minerals were distinctly separated. For this reason, the samples were ground to -0.125 mm to prepare the feed for beneficiation.

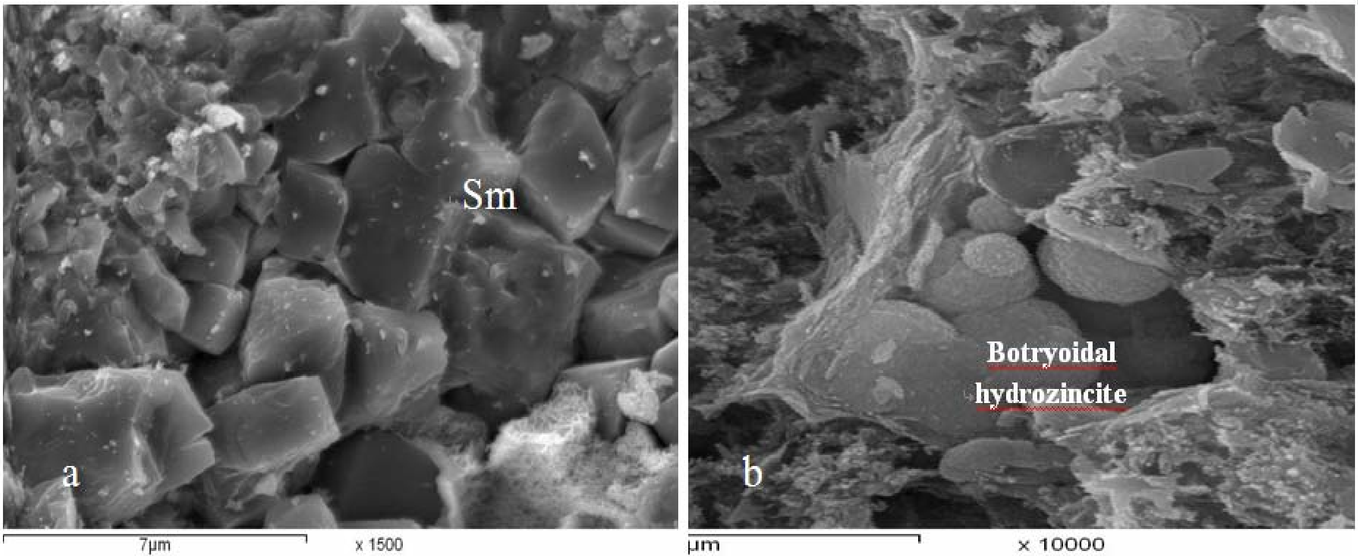
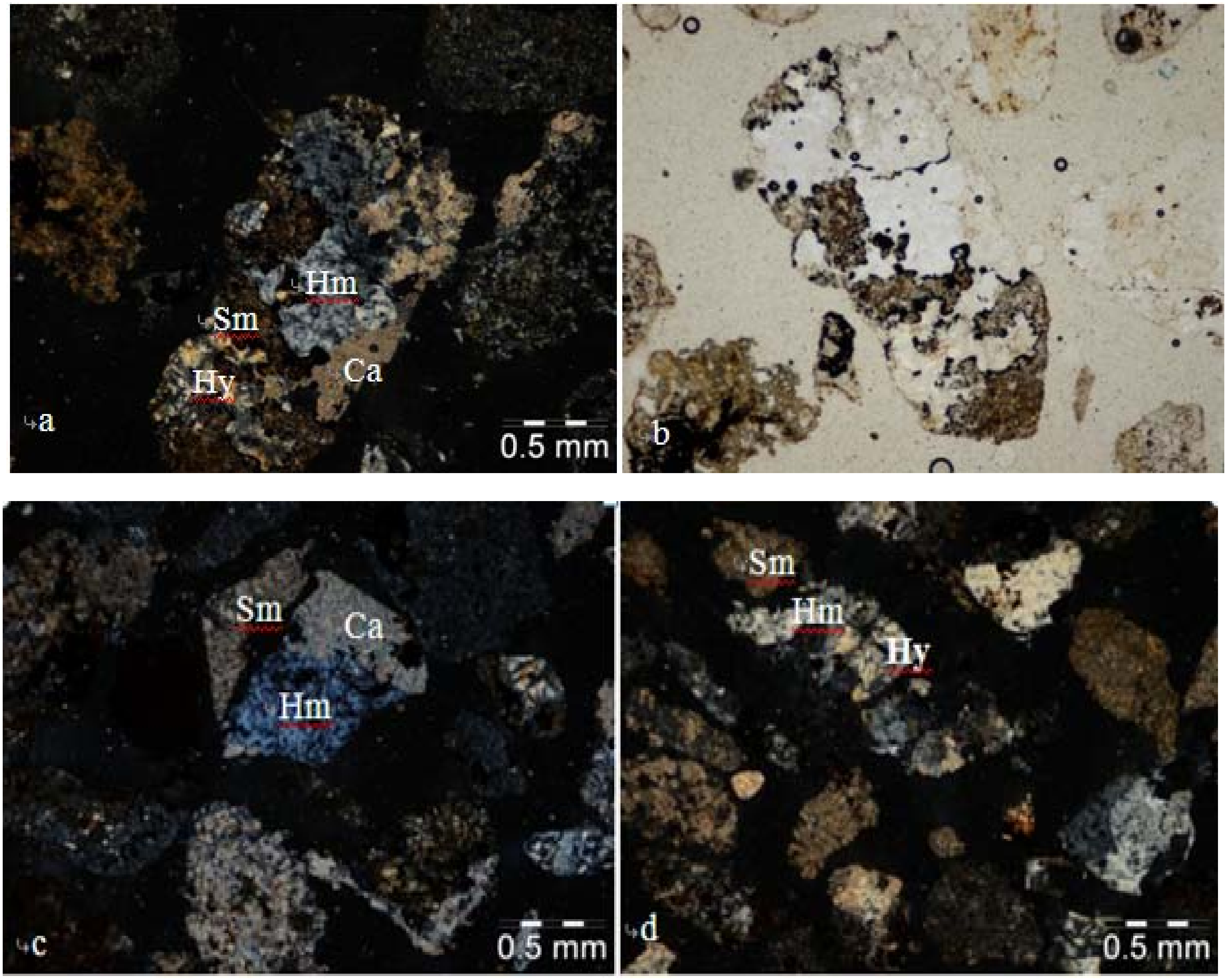


Fig. 5 SEM of samples from Um Gheig nonsulfide deposits a) Rhombohedra crystals of smithsonite (Sm), filling vugs and open space of high grade ore sample c) Botryoidal hydrozincite (Hy) in cavities between smithsonite



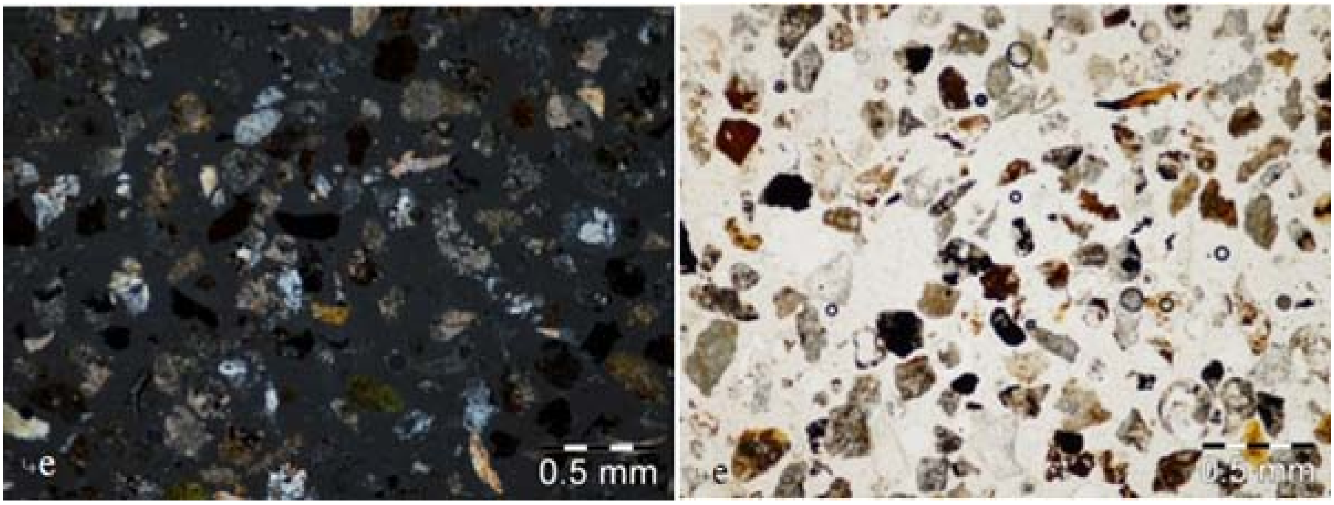


Fig. 6. a) 0.833 mm size fraction shows (composite particale) complex interlocking and growth between non-sulphide Zn minerals (smithsonite, hydrozincite and hemimorphite) and calcite gangue minerals, under CN. b) Same photo in a under PPL. c) 0.589 mm size fraction shows ternary particles of smithsonite (sm), hemimorphite (Hm) and calcite (Ca). d) 0.417 mm size fraction less complex shows simple binary association of smithsonite (sm), hemimorphite (Hm), hydrozincite (Hy) and calcite(Ca). e) 0.106 mm size fraction show that the minerals are separated (free), liberation > 90 %. f) same Photo in e under

C. Separation Using Shaking Table

Due to the difference in specific gravity (sp.gr 3.5-4.5) between non-sulphide zinc minerals (smithsonite, hydrozincite and hemimorphite) with gravity between and the gangue calcite mineral (sp.gr 2.7) gravity separation technique was applied for recovery of zinc minerals (Gupta and Yan, 2006; Wills and Napier-Munn, 2005). For each experiment, the produced concentrates and tails are collected, dried, weighed, and chemically analyzed for ZnO %, CaO % and Fe_2O_3 %.

1) Effect of Inclination Angle:

Fig.7 illustrates the relation between inclination angle, grade and recovery of the shaking table at constant water flow rate 25 l/ min, feed rate 150 gm/min, and stroke length 2.5 cm. It is clearly noticed that, with increasing the inclination angle; the grade and recovery increase and reach to the maximum values at the inclination angle of 4 degrees. At such conditions, the concentrate product has ZnO % and recovery of 62.3% and 92.0 % respectively. On the other hand it is noticed that with increasing the inclination angle above 4 degree the grade and recovery are decreased. This is explained according to that the larger the inclination angle, the more difficult for good distribution of particles on the shaking table.

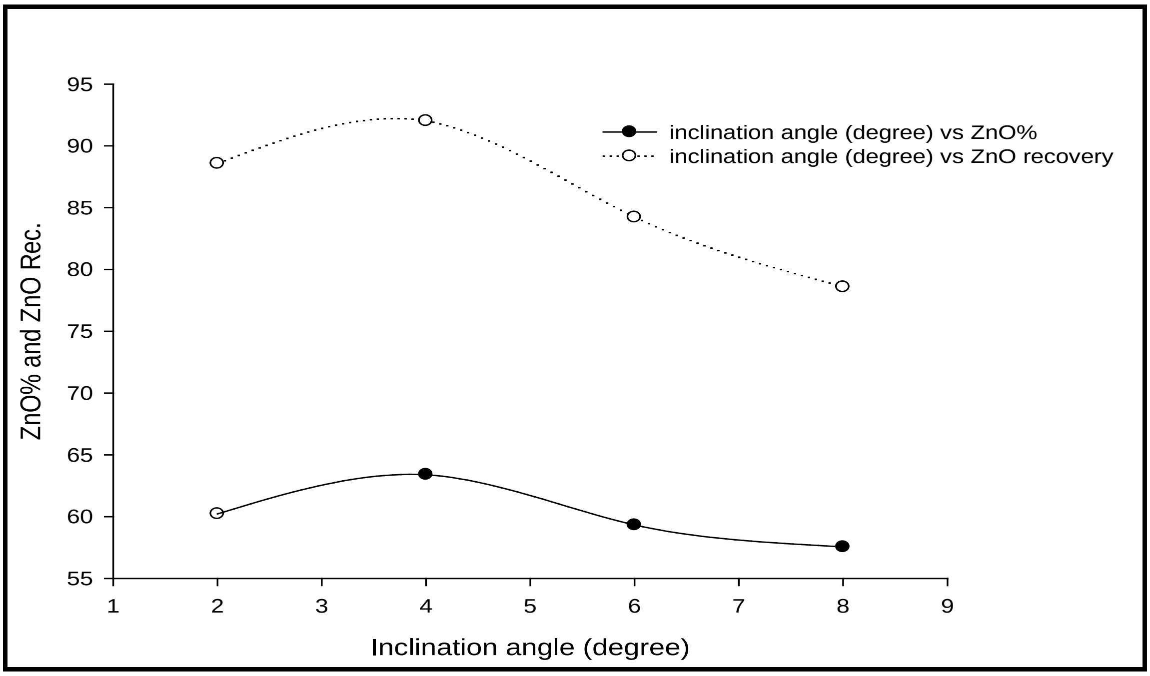


Fig. 7 Inclination angle as a function of ZnO % and Recovery

2) Effect of Stroke Length:

Fig.8 shows the grade and recovery of zinc at different stroke lengths of shaking table and at constant water flow rate 25 l/ min, feed rate 150 gm/min, and inclination angle 4 degree. It is noticed that good separation occurs at small values of the stroke length. This is explained due to the fact that the larger the stroke length, the more disturbance of the particles on the shaking table and hence the more difficult for good separation. The most efficient stroke length is 2.5 cm, at which a

concentrate product with an assay of 60.2 % ZnO, and a recovery of 91.1 % was obtained.

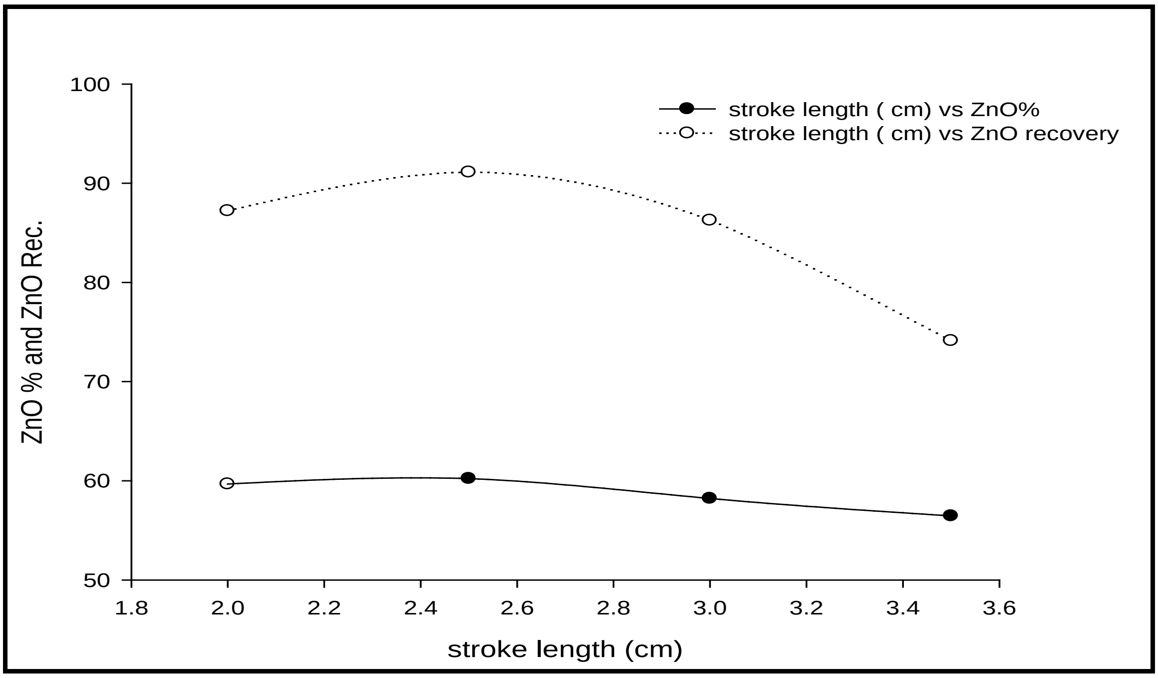


Fig. 8 Stroke length as a function of ZnO % and Recovery

and a recovery of 93.8 %. On the other hand it is noticed that with increasing the feed rate over 150 gm/min, both grade and recovery decrease in a great manner. This could be explained due to the fact that the larger the feed rate, the more crowding of particles on the shaking table, and hence the more difficult for good separation on the shaking table.

3) Effect of Feed Rate:

Fig.9 shows the grade and recovery of zinc as a function of feed rates at constant water flow rate 25 l/ min, inclination angle 4 degrees, and stroke length 2.5cm. It is obvious that the most efficient feed rate is 150 gm/min at which the concentrate product has an assay of 62.2 % ZnO,

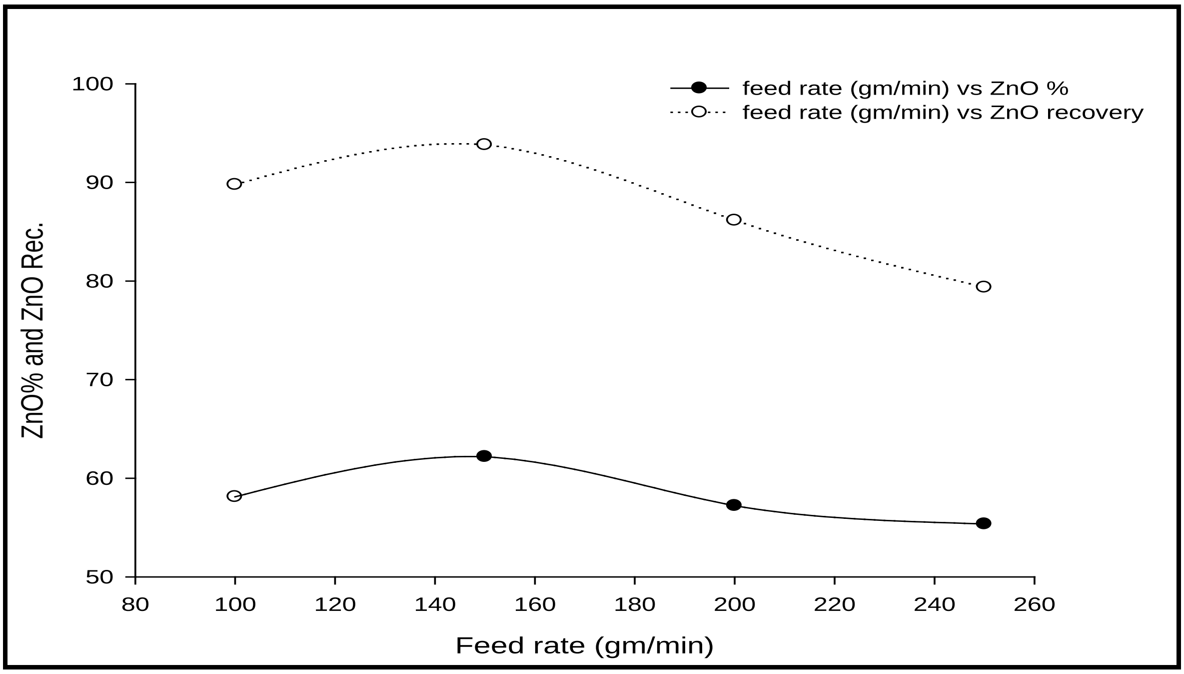


Fig. 9 Feed rate as a function of ZnO % and Recovery

4) Effect of Water Flow Rate:

Fig. 10 shows the grade and recovery of zinc at different water flow rates and at constant feed rate 150 gm/min, inclination angle 4 degree, and stroke length 2.5 cm. It is obvious that the most efficient water flow rate is 25 l/min at which a concentrate product with an assay of 60.9 % ZnO, and a recovery of 90.1 % was obtained.

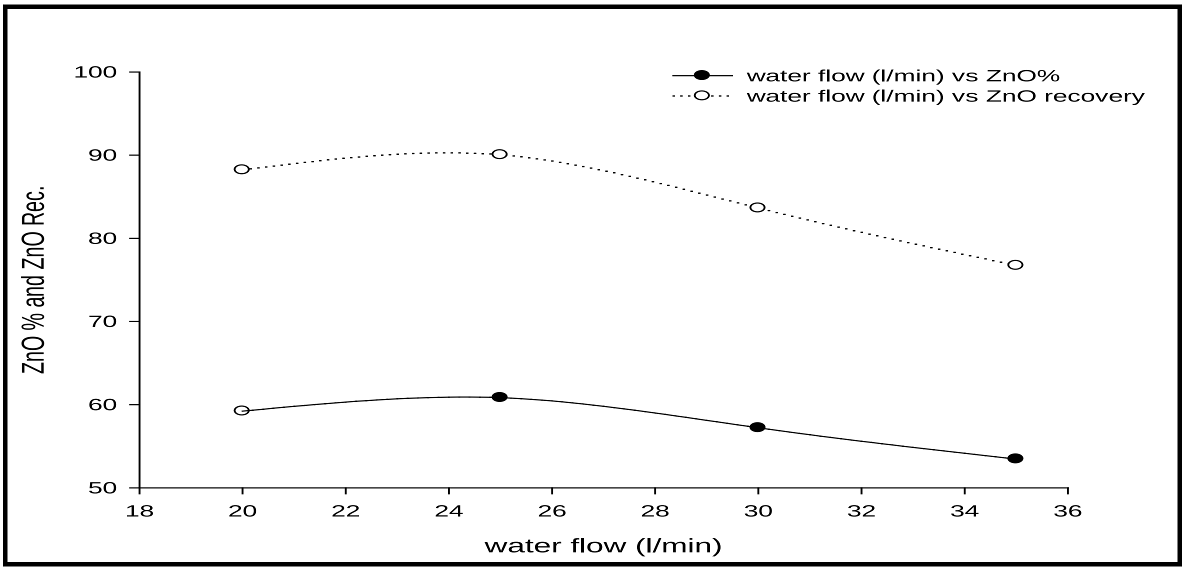


Fig. 10 Water flow rate as a function of grade and recovery

From aforementioned results it can be seen that the best operating parameters to obtain a concentrate with high assay and recovery are at inclination angle (4 degree), stroke length (2.5 cm), feed rate (150 gm/min), and water flow rate (25 l/min). At such optimum conditions a concentrate with about 62.2 % ZnO, and a recovery of 93.8 % was obtained.

C. Separation Using Falcon Concentrator

Due to the limitation of shaking table in separating fine size fractions (- 0.080 mm), Falcon technique was applied for treatment such fines. The different operating parameters affecting the efficiency of separation were optimized (Farag, 2011). The results showed that they are: centrifugal field 200 G's, fluidization water 6 psi, and feed rate 100 gm/min. At such optimum conditions, maximum operational recovery and grade are 76.6% and 54.85 % ZnO respectively are obtained.

The above mentioned results indicated that shaking table technique is efficient for treatment of coarse fractions while Falcon technique is ideal for treatment of fine feed samples.

Ⅳ. CONCLUSIONS

The Um Gheig nonsulfide deposit in the Red Sea Coast Egypt, shares many characteristics with the typical carbonate-hosted calamine-type nonsulfide Zinc ores. Such ore consists mainly of smithsonite, hydrozincite and hemimorphite. Calcite and goethite are the main gangues minerals. Smithsonite [ZnCO3] is the most abundant nonsulfide zinc. Hydrozincite [Zn5(CO3)2(OH)6] is less abundant compared with smithsonite. Hemimorphite [Zn4Si2O7(OH)2.H2O] is quite abundant. Liberation study indicated that high degree of mineral liberation (> 90 %) can be attained at 0.106 mm in size, where individual component are distinctly separated.

The experimental beneficiation techniques involved crushing, grinding, and classification to prepare a feed suitable for the separation process. Gravity separation process using "shaking table" was applied to separate the zinc bearing minerals from their associated gangues. Shaking table technique is applied on the feed size of -0.125 +0.080 mm size fractions. Four parameters are studied, namely inclination angle, stroke length, feed rate and water flow rate. The results show that, the optimum parameters are inclination angle (4 degree), stroke length (2.5 cm), feed rate (150 gm/min), and water flow rate (25 l/min). At such optimum conditions maximum grade (62.2 % ZnO) and recovery (~ 93.8 %) can be obtained from a feed sample assaying ~ 47.6 % ZnO.

Falcon technique was applied for treatment of fines below 0.080 mm. The results showed that a second concentrate with 54.85 % ZnO and operational recovery 76.6% was obtained.

The above mentioned results indicated that shaking table technique is efficient for treatment of coarse fractions while Falcon technique is ideal for treatment of fine feed samples.

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